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Summary of the Geology, Economic Aspects, and Geochemistry of the Schwartzwalder Uranium-bearing Area, Ralston Buttes District, Jefferson County, Colorado

U.S. GEOLOGICAL SURVEY BULLETIN 1555

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Summary of the Geology, Economic Aspects, and Geochemistry of the Schwartzwalder Uranium-bearing Area, Ralston Buttes District, Jefferson County, Colorado

By E. J. YOUNG

U.S. GEOLOGICAL SURVEY BULLETIN 1555

A study of relations between uraniferous mines and prospects in the Front Range near Golden, Colorado

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SUMMARY OF THE GEOLOGY, ECONOMIC ASPECTS, AND GEOCHEMISTRY OF THE SCHWARTZWALDER URANIUM–BEARING AREA, RALSTON BUTTES DISTRICT, JEFFERSON COUNTY, COLORADO

By E. J. YOUNG

ABSTRACT

The most productive vein uranium deposit in the Colorado Front Range and, indeed, in the United States is the Schwartzwalder. Ultimate production may be 10 million kg U_3O_8, or more. The Schwartzwalder deposit is 13 km southeast of the Front Range mineral belt, in Precambrian metamorphic country rocks, but is less than 0.8 km distant from sedimentary rocks ranging in age from Pennsylvanian to early Tertiary. After at least three episodes of Precambrian folding succeeded by an episode of faulting that produced northwest-trending faults, the Laramide orogeny caused upturning and folding of sedimentary strata along the mountain front, reactivated the Precambrian northwest-trending faults, and initiated new faulting and fracturing in the Schwartzwalder area. During Laramide time, about 62 m.y. ago, the Ralston dike, of mafic monzonite, was intruded along the Golden fault.

The Precambrian rocks consist of metamorphosed sedimentary and volcanic rocks (mica schist, quartzite, hornblende gneiss, granite gneiss, and a magnetite and quartz layer), cataclastic rocks (granite gneiss and biotite schist), igneous and metaigneous rocks (pegmatite, hornblende diorite, and hornblendite), and quartz veins. Paleozoic sedimentary rocks consist of the Pennsylvanian and Permian Fountain Formation and the Permian Lyons Sandstone. A small mafic monzonite dike of Laramide age occurs 1.9 km northwest of the Schwartzwalder; the Ralston dike is 3.6 km southeast. Several Quaternary surficial deposits complete the geologic succession.

The major fold of the mapped area is a steeply dipping, asymmetric synform in mica schist that plunges 45°-68° west-southwest. The compressed apical part of the synform is the country rock for almost all the pitchblende veins in the Schwartzwalder deposit. The northeasterly striking Idaho Springs–Ralston shear zone is probably a limiting boundary for uranium mineralization. A set of northwest-trending breccia-reef faults showing little or no displacement is interpreted as the conduit for uranium migration.

The Schwartzwalder is a prime example of a structurally controlled ore deposit. Shearing, developed in the cymoid zone of the Illinois fault, produced the opening of many horsetail fractures, which provided sites for uranium deposition about 60 m.y. ago. Pyrite and minor amounts of lead, molybdenum, and zinc sulfides accompany the

pitchblende, which contains significant amounts of high-valent elements, such as antimony, tungsten, and thallium.

The Mena and North Star Mines of the Ralston Buttes district differ from the Schwartzwalder in being very small producers and richer in bismuth, copper, and silver than in uranium. The ores from six additional prospects show geochemical affinities to the Mena and North Star Mines rather than to the Schwartzwalder.

Geochemical data in and around the Schwartzwalder deposit suggest that the surface country rocks (mainly Precambrian schists and gneisses) are not the source of the uranium and base metals. Underground host rocks of the same lithotypes show enrichment in 11 elements, similar to the enrichment in the pitchblende veins, because of infiltration of ore fluids through microfractures in proximity to the pitchblende veins. Fault breccias, both underground and surface, also show enrichment in the same elements as the pitchblende veins.

INTRODUCTION

The Schwartzwalder uranium deposit has become the most productive vein uranium deposit in the Front Range and, indeed, in the United States. Total production is about 5 million kg U_3O_8, and ultimate production may be more than twice that amount. About 97 percent of all uranium produced from veins in the Front Range has come from this ore deposit.

The Schwartzwalder Mine is about 13 km northwest of Golden in the SE ¼ sec. 25, T. 2 S., R. 71 W., in the Ralston Buttes district, Jefferson County, Colo. (fig. 1).

Detailed geologic and radiometric mapping of 18 km^2 (area shown on fig. 2) was undertaken intermittently from 1973 to 1975 on a 1:12,000 topographic base. The main objective was to map the Schwartzwalder area in greater detail than heretofore. (See plates 1 and 2.)

A description of the Schwartzwalder Mine and a smaller area (3.4 km^2) around the mine was released previously (Young, 1977). A report on the genesis of the Schwartzwalder deposit (Young, 1979b) and a tabulation of analytical data (Young, 1979a) were recently published. The most detailed published map of the Ralston Buttes district is that of Sheridan and others (1967) at a scale of 1:24,000.

REGIONAL GEOLOGIC SETTING

The Schwartzwalder deposit is in the east-central part of the Front Range, about 13 km southeast of the northeast-trending Front Range mineral belt. Figure 2 shows generalized geology in the vicinity of the Schwartzwalder Mine and the inactive Mena and North Star Mines. Although the uranium deposits occur in Precambrian metamorphic country rocks, the Schwartzwalder deposit is less than 0.8 km distant from sedimentary rocks ranging in age from Pennsylvanian to early Tertiary. The proximity of the deposit to the sedimentary rocks is thought to be significant. (See fig. 6.)

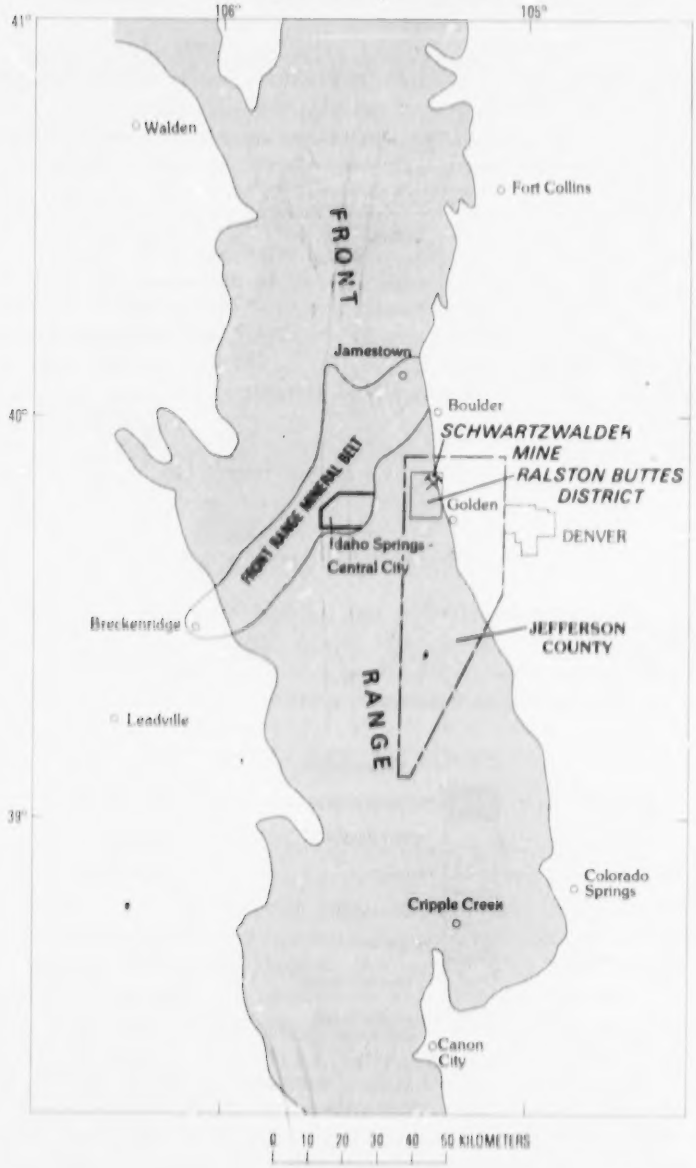

FIGURE 1.—The Front Range, Colo., location of the Ralston Buttes district, Schwartzwalder Mine, and Front Range mineral belt (from Sheridan and others, 1967, fig. 2).

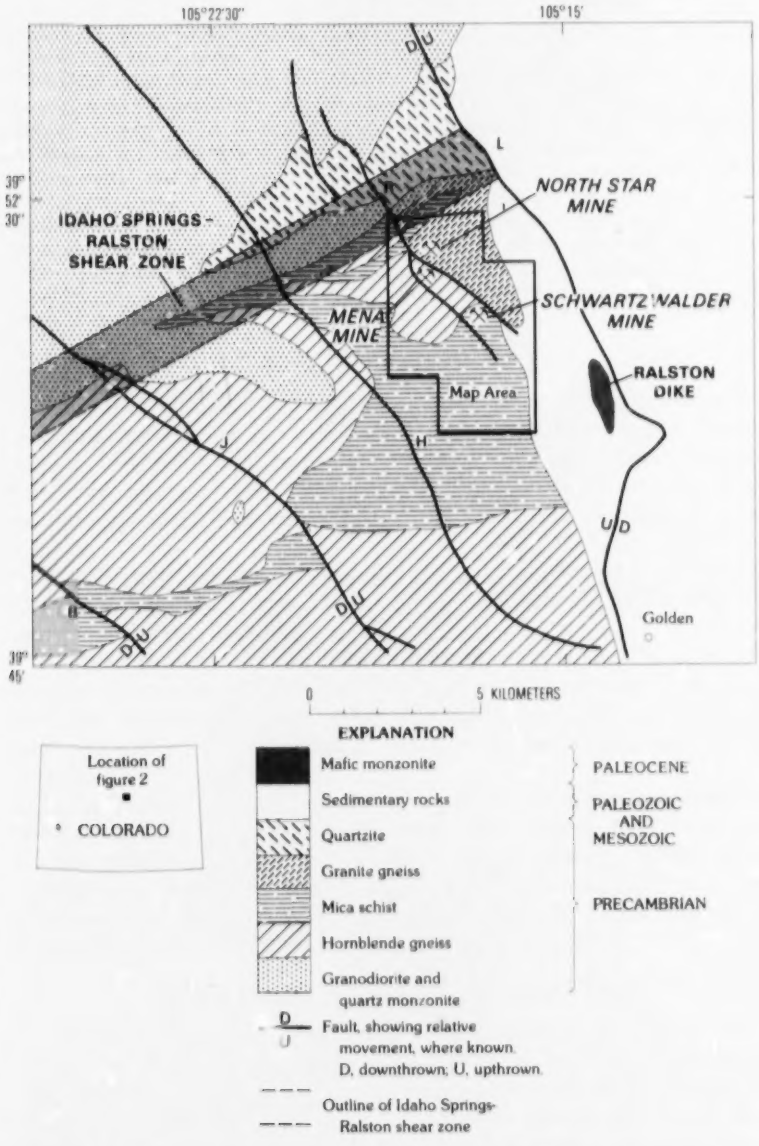

FIGURE 2.—Location of map area and regional geology. Precambrian faults are identified as follows: B, Black Hawk; J, Junction Ranch; H, Hurricane Hill; R, Rogers, east and west branches; L, Livingstone (southern extension of Livingstone fault is known as the Golden fault in Golden area). (Modified from Taylor, 1975.)

Three periods of Precambrian folding, succeeded by northwest-trending faulting (also Precambrian), have been recognized in the region (Taylor, 1975). The sedimentary succession that flanks the Precambrian core of the range begins with the Pennsylvanian and Permian Fountain Formation, which was deposited directly on the Precambrian basement following a long erosional interval. This unconformity is characterized by a relatively soft, red, weathered zone (regolith) as much as 6 m thick in the Precambrian rocks. Laramide uplift of the Front Range began in Late Cretaceous time (67 m.y. ago) and generally ceased in the middle Eocene (45 m.y. ago). This orogeny caused upturning and folding of the sedimentary strata along the mountain front, reactivated the Precambrian northwest-trending faults, and initiated new faulting and fracturing in the Schwartzwalder area and elsewhere. The Ralston dike, of mafic monzonite, and several related, smaller intrusions were emplaced in or near the Golden fault about 62 m.y. ago during late stages of movement on the Golden fault (Van Horn, 1976).

ROCKS OF THE MAP AREA

Predominant rocks of the map area (pl. 1) are Precambrian crystalline rocks (formerly called Idaho Springs Formation—see Tweto, 1977), Paleozoic sedimentary rocks, and Cenozoic surficial deposits. Tertiary igneous intrusive rocks are represented by one small dike.

PRECAMBRIAN ROCKS

METAMORPHOSED SEDIMENTARY AND VOLCANIC ROCKS

Biotite-muscovite schist (Xs).—The schist unit occupies the southern half of the map area. The north boundary of the schist is a transitional contact with hornblende gneiss. On the east, the schist is overlain unconformably by the eastward-dipping Pennsylvanian and Permian Fountain Formation. Beneath the contact with the Fountain the schist shows a soft, red, weathered zone (regolith) as much as 6 m thick. The schist is commonly fine grained (0.1–1.0 mm) and contains at least 14 minerals, but not all in any one specimen (table 1). About half of the schist is composed of quartz, suggesting a clastic, metasedimentary origin. Pegmatites are more common in the schist than in any other rock unit. Porphyroblasts of andalusite attain lath sizes of 60×2.5 cm in the western part of the area, but most appear as knobby relicts, 1 or 2 cm in length, in outcrops. Staurolite is not as abundant, but appears as knobby dark brown relicts as large as 1 cm in length in outcrops. Fine-grained, black tourmaline locally forms a significant part of the schist and has been found as fillings

TABLE 1.—*Average modal mineralogy of major rock units in the Schwartzwalder area*

[Shown in volume percentages. Tr., trace; leaders (--) indicate not present]

Map symbol-------	Xs	Xq	Xh	Xqg
Quartz----------	48	75	17	44
Muscovite--------	14	4	--	2
Biotite----------	18	11	5	4
Hornblende-------	--	--	36	--
Plagioclase------	6	--	35	36
Potash feldspar--	--	1	--	13
Garnet-----------	2	5	1	--
Chlorite---------	1	--	2	--
Tourmaline-------	2	--	--	--
Black opaque-----	1	3	1	Tr.
Sillimanite------	1	--	--	--
Andalusite-------	6	Tr.	--	--
Staurolite-------	Tr.	Tr.	--	--
Calcite----------	Tr.	Tr.	2	Tr.
Pyrite-----------	--	--	Tr.	Tr.
Apatite----------	Tr.	Tr.	Tr.	Tr.
Sphene-----------	--	Tr.	Tr.	--
Zircon-----------	Tr.	--	--	--
Thin sections contributing to average-------	11	7	3	5

in small fractures. Crenulations, crinkles, and minor folds, characterized by parallel arrangement of biotite and muscovite flakes, are common.

Magnetite and quartz layer (Xm).—The magnetite-quartz layer in the northern part of the schist unit is about 1.5 km long but less than 6 m thick. It consists of several thin alternating layers of magnetite and quartz interlayered conformably in schist. Each magnetite-quartz layer is about 15 cm thick, but solid magnetite blocks (float) as much as 20 cm across have been found. The unit is poorly exposed. A syngenetic, metasedimentary origin (iron-formation) of the magnetite and quartz layer is suggested not only by its conformability, but also by the high Mn content (>5000 ppm) and relatively low Ti (500 ppm) and Cr (<10 ppm) content of the magnetite.

Quartzite (Xq).—The quartzite unit occurs in conformable lenslike bodies close to the transitional contact of hornblende gneiss and schist and in a much larger conformable lens in the northwest part of the hornblende gneiss. The quartzite is fine grained (average grain size <1 mm), is variable, and contains from about 60 to 95 percent quartz. Fine-grained biotite and muscovite flakes generally define a pronounced foliation. Each mapped quartzite lens is either all quartzite

or is interfoliated with its host rock. Magnetite and hematite are common accessory minerals.

Hornblende gneiss (Xh).—The main body of hornblende gneiss occupies the central part of the map area. The northern contact of hornblende gneiss is transitional into granite gneiss, and the southern boundary is transitional into mica schist. Near the Schwartzwalder Mine on the northeast side of Ralston Creek, hornblende gneiss forms a salient that crosses the east branch of Roger's fault. This salient is interpreted to be the nose of the southward-plunging synform that provides the structural control of the Schwartzwalder deposit. Several smaller bodies of hornblende gneiss occur in the northern part of the map area. The hornblende gneiss is fine to medium grained (average grain size is 1 mm). Hornblende, plagioclase, and quartz compose about 90 percent of the rock. Epidote is common locally. White, crystalline float blocks of marble as much as 30 cm across were seen in the northern outcrop area of the hornblende gneiss. Forms from 45 to 60 cm across, interpreted to be relict pillow lava, were noted in the east-central part of sec. 26, T. 2 S., R. 71 W., at the foliation symbol dipping 42° to the west (pl. 1). The hornblende gneiss unit is probably volcanic in origin.

Granite gneiss (Xgg).—The granite gneiss unit occupies the east-central part of the map area. Its southern border is transitional into hornblende gneiss, and on its northern border granite gneiss merges with the interlayered granite gneiss and hornblende gneiss unit. A conspicuous feature of the transitional contact between granite gneiss and hornblende gneiss is the greater abundance of pegmatites than elsewhere. As shown on plate 1, this zone is about 300 m wide. At several places in sec. 25, T. 2 S., R. 71 W., granite gneiss occurs as conformable lenses in hornblende gneiss, where it is very fine grained and aplitic in texture. The granite gneiss is pink to pinkish gray and very fine to fine grained (average grain size <1 mm); more than 90 percent of the rock is composed of feldspar and quartz. Locally, biotite is sufficiently abundant to darken the rock perceptibly. Augen texture is developed along the transitional contact with hornblende gneiss, and it is well developed on Ralston Creek in the NW ¼ sec. 25, T. 2 S., R. 71 W. A very high quartz content suggests a metasedimentary origin for the granite gneiss.

Granite gneiss and hornblende gneiss (Xggh).—This rock unit is composed of roughly equal parts of granite gneiss and hornblende gneiss, interfoliated complexly and having individual units from 1 m to 10 m thick. Consequently, separation of the two rock units is not practical at the map scale (1:12,000). The rock unit grades into granite gneiss to the south and into cataclastic granite gneiss of the Idaho Springs–Ralston shear zone to the northwest. The northeast strike

of foliation in much of the granite gneiss and hornblende gneiss unit is interpreted to be the effect of cataclasis.

CATACLASTIC ROCKS

Granite gneiss (Xggc).—The cataclastic granite gneiss forms two northeast-trending zones in the northwest part of the map area. It is a pink to pinkish-gray, fine-grained (average grain size is 1 mm) rock having a marked foliation that has resulted from granulation and shearing. In thin section, mortar structure and granulation are well developed. These cataclastic features are well defined in the cataclastic granite gneiss, but cataclasis also affects the granite gneiss and hornblende gneiss to the south as it gradually diminishes from north to south. Compositionally, the cataclastic granite gneiss is similar to the granite gneiss unit and is, therefore, interpreted as granite gneiss that has undergone cataclasis.

Biotite schist (Xbsc).—The cataclastic biotite schist unit in the northwest part of the map area occurs between zones of granite gneiss and hornblende gneiss. It is fine to medium grained and, in addition to abundant crinkled biotite, it commonly has small, pink porphyroblasts of feldspar. Felsic laminae are abundant locally. Mortar and flaser structures are especially evident in thin section.

IGNEOUS AND METAIGNEOUS ROCKS

Pegmatite (Xp).—Pegmatite occurs in almost all the Precambrian rock units, but it is most plentiful and widespread in the schist unit. Another zone of abundant pegmatite concentrate occurs in the general contact area between the hornblende gneiss and the granite gneiss. Almost all of the pegmatite bodies are lenslike and conformable, but a small number are crosscutting. The largest ones in the northwest part of the map area are complex in structure and contain septa of host rock. The pegmatites are coarse grained and consist mostly of microcline, perthite, quartz, and biotite with minor muscovite. Black tourmaline is a common accessory mineral; magnetite is less common. Apatite, chrysoberyl, columbite, and cleavelandite are uncommon minerals. The interpretation by Sheridan and others (1967) that many pegmatite bodies in the Ralston Buttes district are related to the Silver Plume Granite is strengthened by a potassium-argon age determination of 1,450 m.y. on muscovite from a pegmatite in the Schwartzwalder Mine (R. F. Marvin, H. H. Mehnert, and Violet Merrill, written commun., 1973). This 1,450-m.y. age determination may be either a primary age or a minimum age. The date correlates well with the 1,390- to 1,450-m.y. ages of the Silver Plume and related granite obtained by Peterman and others (1968) using rubidium-strontium methods.

Hornblende diorite and hornblendite (Xhd).—Several bodies of hornblende diorite and hornblendite occur in the northeastern part of the map area. Contacts with enclosing granite gneiss and hornblende gneiss are fairly abrupt. Grain size varies from fine to coarse (<1 mm to >1 cm); hornblende and plagioclase (~An_{50}) compose most of the rock. Although more massive than surrounding granite gneiss and hornblende gneiss, the hornblende diorite shows a foliation that commonly is at right angles to that of the host rock. The relative massiveness of the hornblende diorite and hornblendite, in comparison to their host rock, probably protected their earlier impressed foliation and resisted the pervasive, northeast cataclasis that affected the host rock.

Quartz veins (Xqt).—Four massive quartz veins have been mapped in the schist unit. Most are conformable, but the one along the west branch of Rogers fault in the northern part of sec. 36, T. 2 S., R. 71 W., is nonconformable to host-rock foliation. The quartz is generally white and clean; it is fine to coarse in grain size (<1 mm to >1 cm). The veins are as much as 2 m wide and attain lengths of as much as 30 m.

PALEOZOIC SEDIMENTARY ROCKS

Pennsylvanian and Permian: Fountain Formation (PPf).—The Fountain Formation unconformably overlies Precambrian rocks in the eastern part of the map area as an eastward-dipping monocline; however, it is folded in secs. 30 and 31, T. 2 S., R. 70 W., to form a syncline and anticline, both plunging southeast. The west limb of the anticline and the northern end of the syncline form a fault slice wedged between Precambrian rocks. The Fountain Formation consists of pink to reddish-orange arkosic sandstone and conglomerate and dark-reddish-brown mudstone and sandstone.

Permian: Lyons Sandstone (Ply).—The Lyons Sandstone occurs in the east-central part of the map area as part of a southeast-plunging syncline, where it lies conformably on the Fountain Formation. The Lyons Sandstone is a light-gray to grayish-orange, crossbedded, clean and well-sorted, fine- to medium-grained quartzose sandstone in the map area.

TERTIARY INTRUSIVE ROCKS

Mafic monzonite (Tmm).—A thin dike of severely altered mafic monzonite occurs in the northeast quarter of sec. 23, T. 2 S., R. 71 W., and a similar dike occurs in the southeast quarter of the same section. Both dikes are probably outcrops of the same body and were intruded in late Laramide time. The one in the southeast quarter of sec. 23 is at least 1.2 m thick and has been traced for 46 m. It strikes approximately N. 20° W. and dips 20° E. It intrudes granite

gneiss and hornblendic rock, which shows segregations of marble as much as 30 cm across and large (several centimeters) hornblende crystals in vugs. Malachite occurs nearby in hornblendic rock. The dike rock is dark brown and has a pronounced spheroidal weathering. Fresh rock is aphanitic and markedly magnetic. A thin section of hard, relatively fresh rock shows an olive drab groundmass interspersed with small (~0.7 mm) olive drab spheroids of chlorite, which are probably weathered remnants of olivine and augite, and an overall felty texture produced by abundant platy microlites of plagioclase (An_{52}). About one tenth of the rock consists of irregularly shaped potassic feldspar phenocrysts several millimeters in size, contributing a porphyritic aspect to the texture.

The dike in the northeast quarter of the same section has been traced for at least 170 m, striking about N. 5° W. It dips east at approximately 55° and is between 3 and 4 m thick. The dike is probably similar in composition to the Ralston dike, which is a mafic monzonite. Chemical and spectrographic analyses of the Ralston dike have been reported by Young (1979a).

CENOZOIC SURFICIAL DEPOSITS

QUATERNARY DEPOSITS

PLEISTOCENE, LOWER

Rocky Flats Alluvium (Qrf).—A small deposit of coarse, bouldery, cobble gravel is located on a grassy knoll in the west-central part of sec. 31, T. 2 S., R. 70 W. Because it consists largely of quartzite cobbles and boulders and lies at the same elevation as the Rocky Flats Alluvium mapped in the extreme northeast corner of the Ralston Buttes quadrangle by Sheridan and others (1967), it is interpreted to be that unit.

PLEISTOCENE, UPPER

Louviers Alluvium (Qlo).—Deposits of Louviers Alluvium in the southeastern part of the map area form grassy benches underlain by silty, fine-grained sand that is coarser at depth.

Broadway Alluvium (Qb).—The Broadway Alluvium in the southeastern part of the map area, as recognized by Sheridan and others (1967), is composed of silty, cobbly gravel and coarse sand.

HOLOCENE

Piney Creek Alluvium and post-Piney Creek alluvium (Qal).—These two alluviums have not been differentiated. They are found along portions of Ralston Creek and its tributaries.

STRUCTURAL GEOLOGY

STRUCTURE OF PRECAMBRIAN ROCKS

FOLDING

The major fold in the map area is expressed in mica schist, which is the country rock for the pitchblende-bearing fractures in the Schwartzwalder deposit (pl. 1). This fold is a steeply dipping synform that has an overturned west limb. Figure 3 is a contoured plot of poles to all the foliations (633) given on plate 1. The poles form a girdle (great circle) whose perpendicular axis is a line striking S. 85° W. and plunging 58°. This calculated line agrees well with the

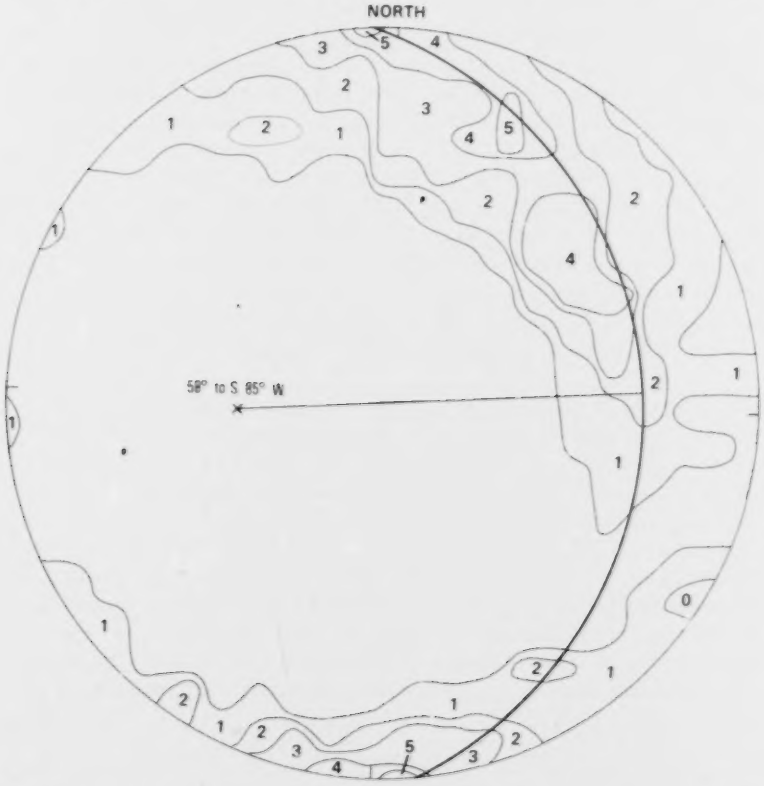

FIGURE 3.—Lower hemisphere projection of 633 poles to foliation on equal-area net, contoured in percent of poles per percent area. The poles form a girdle (great circle) whose perpendicular axis is a line striking S. 85 W. and plunging 58°. X marks the emergence of the perpendicular axis into the lower hemisphere.

maximum concentration of 58 measured lineations shown in figure 4. The northern portion of the synform manifests itself both on the surface and underground as a compressed tongue of schist containing garnetiferous zones and quartzite lenses. It evidently represents a compressed apical part of the synform, and by tracing its axis on the surface to the northeast its structure is shown by a tailing-out of the thin wedge of hornblende gneiss that encloses the schist tongue.

The quartzite body in the western part of the map area defines a minor southwest-plunging synform.

The general northwest-trending foliation of the granite gneiss becomes northeasterly to the north as a result of the shearing along the Idaho Springs–Ralston shear zone.

FIGURE 4.—Lower hemisphere projection of 58 lineations on equal-area net, contoured in percent of poles per percent area. X marks the emergence of the perpendicular axis into the lower hemisphere.

IDAHO SPRINGS–RALSTON SHEAR ZONE

This distinctive structural zone, formed after Precambrian folding and located in the northwest part of the map area, was named and discussed by Tweto and Sims (1960; 1963, p. 998–1000). The intense shearing, as indicated by the cataclastic granite gneiss and the cataclastic biotite schist within the zone, is also evident in the granite gneiss and hornblende gneiss that lie to the south of it.

BRECCIA REEFS

The northern half of the map area contains a set of parallel to subparallel, northwest-trending fracture zones called breccia reefs and breccia dikes (Lovering and Goddard, 1950, p. 79). These late Precambrian fracture zones may be faults of indeterminate or small displacement, and they are characterized by steep dips and breccia zones as much as 100 m wide. Their usual surface expression is a rubble of loose, yellow-brown altered rocks, but locally is a wall-like outcrop of resistant breccia, such as the one in the SE ¼ sec. 25, T. 2 S., R. 71 W., which has an approximate dip of 75° to the east. The breccia weathers to a rough surface on which fragments of wall rock, ankerite, potassic feldspar, and quartz stand out in relief. More commonly, where breccia reefs cross ridges, the site is marked by a topographic depression or saddle. Positive or negative relief of the breccia reefs is generally a function of silicification. Actual observed sites of breccia outcrop or rubble are marked in plates 1 and 2. The breccia reef 200 m northeast of the east branch of Rogers fault is also marked by two springs.

The relative displacement along the breccia reefs in the map area is insignificant megascopically, and hence, as mentioned by Sheridan and others (1967, p. 70–71), the term fracture zone is more appropriate than fault. Apparent lateral movement on the east and west branches of Rogers fault is negligible, because the hornblende gneiss is not displaced where it crosses the east branch (fig. 5), and the magnetite and quartz layer is not displaced where it crosses the west branch. Vertical movement on the east branch is also probably small. Sheridan and others (1967) indicated an apparent horizontal displacement of 670 m on the east branch, but if my interpretation of a fold in the Fountain Formation is correct, there is no appreciable horizontal displacement.

OTHER FAULTS

Two other kinds of faults in the Schwartzwalder area differ sufficiently from the breccia reefs to merit separate mention. The first of these is the Illinois fault, which is the main vein of the Schwartzwalder deposit; it is persistent underground, but not as long or as wide

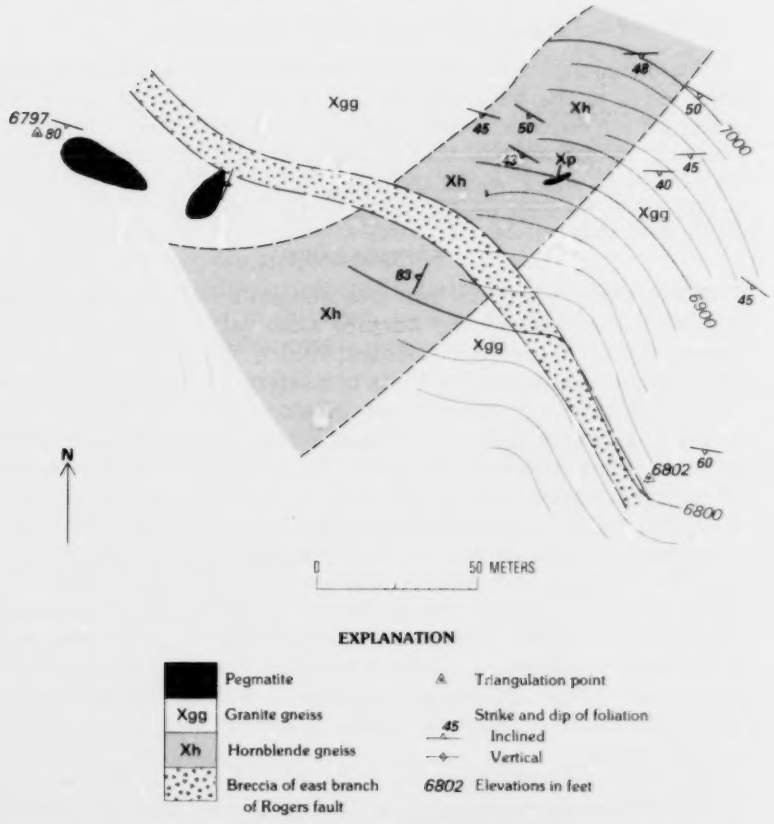

FIGURE 5.—Plane table map of critical area in SE¼ sec. 25, T. 2 S., R. 71 W., where hornblende gneiss crosses east branch of Rogers fault with no apparent displacement. Topography and geology by Kenneth Segerstrom and E. J. Young, 1975.

as the breccia reefs. It dips steeply (about 75 degrees) to the west and forms a cymoid of the following character: its southeast extremity strikes northwest; its middle, ore-bearing portion strikes north, in conformity with its schist host; and its northwest extremity turns northwest and probably follows the valley of Ralston Creek. Observed displacements in the Illinois fault are not large (<2 m), and conflicting evidence of movement in the fault suggests that movement was probably recurrent and in different directions. The Washington fault, about 40 m to the east, is the same type of fault, but is much smaller.

The second type of fault is represented by northeastward-dipping fractures on the hanging wall side of the Illinois fault. Some of these

intersect the surface, but other deeper ones do not. These faults are generally narrow wrench or shear faults showing the least displacement of the three types of faults. Most, if not all, of their movement probably occurred in Laramide time.

FOLDS AND FAULTS IN PALEOZOIC ROCKS

The Laramide orogeny caused folding in the Paleozoic rocks and rejuvenated faults in the northwest-trending breccia reefs.

The Fountain Formation and the Lyons Sandstone are folded into a southeast-plunging syncline in the east-central part of the map area. This folding buckled the Fountain Formation around the granite gneiss bulwark and resulted in a fault slice between two Precambrian blocks. Renewed Laramide movement on the east branch of Rogers fault may have further displaced the fault slice.

RADIOMETRIC AND MINERALOGIC DATA

A radiometric survey covering the map area was done using a handheld scintillometer (Mount Sopris Instrument Company, Model SC–131) containing a 3.8×3.8-cm crystal detector.[1] The readings are expressed in counts per second (cps) and are shown on plate 2. To evaluate counts per second in terms of equivalent uranium (eU), the following approximate relation may be used: 5 cps=1 ppm as derived from analyzed rocks. The term eU represents the summation of radioactivity from the rock and does not discriminate between contributions from uranium, thorium, and potassium.

Relatively high readings from veins and other hot spots, shown on plate 2, are almost entirely due to uranium and its daughter products. As may be seen from plate 2 and table 2, each rock unit has characteristic radiometric readings; and, therefore, radiometry may sometimes be an aid in differentiating rock types in the field whenever such rock tends to be nondescript due to very fine grain size, alteration, or tectonic strain.

Mineralogic data of various kinds are shown on plate 2. Malachite distribution, indicating copper, is mostly confined to breccia reefs. Some pegmatites within the mica schist contain apatite, columbite, and chrysoberyl. Coarsely crystalline tourmaline (schorl) is common to pegmatites in all rock types, but fine-grained tourmaline was only noted in pegmatites within the schist. The distribution of metamorphic minerals—staurolite, andalusite, sillimanite, and garnet—is shown in the schist.

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[1]Use of this brand name is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

TABLE 2.—*Scintillometer readings in counts per second of rocks in the Schwartzwalder area*

	Counts per second		Number of readings contributing to average
	Average	Range	
Vein quartz	55	50- 60	3
Hornblende diorite	55	40- 85	15
Quartzite	57	35-180	11
Lyons Sandstone	65	65	2
Hornblende gneiss	65	15-160	183
Mafic monzonite	70	70	1
Magnetite and quartz	90	90	1
Pegmatite	131	75-275	92
Aplite in hornblende gneiss	175	120-300	5
Biotite schist, cataclasized	179	140-230	13
Schist	181	120-290	286
Granite gneiss, cataclasized	195	140-290	18
Fountain Formation	242	150-360	32
Granite gneiss	255	160-440	90
Fault breccia (in hornblende gneiss)	112	55-205	16
Fault breccia (in granite gneiss)	221	155-300	10
Fault breccia (in schist)	225	155-320	6

ECONOMIC GEOLOGY

SCHWARTZWALDER MINE

The Schwartzwalder is the most productive uranium vein deposit in the United States. To date, about 5 million kg U_3O_8 (11 million pounds) has been produced, which represents about 97 percent of the uranium mined from the Front Range. Ultimate production may be more than twice that amount.

In this section only a brief resume is given. The following reports should be consulted for more detail: Downs and Bird (1965), Sheridan and others (1967), Derzay and Bird (1976), and Young (1977, 1979a, and 1979b).

The Schwartzwalder deposit, named for Fred Schwartzwalder, who discovered its uranium potential in 1949, was known as a copper prospect before its uranium potential was discovered. In 1953 the first ore shipments were made by Mr. Schwartzwalder, and in 1956 the Denver–Golden Oil and Uranium Company purchased the property. In 1965 the Cotter Corporation acquired the property, and in 1974 the Cotter Corporation became the wholly owned subsidiary of Commonwealth Edison Company.

The structural framework for the deposit is defined by a fracture system that provided an abundance of openings for infiltration by uranium-bearing solutions. The deposit is bounded on the northeast and southwest by northeastward-dipping (~75°) breccia reefs of the Ro-

gers system. Lying about midway between the breccia reefs is the cymoid Illinois fault. The Illinois fault strikes north through the productive part of the mine area, but at its extremities bends to a northwest strike. Unlike the breccia reefs, it dips westerly (~75°). The Illinois fault, mineralized along most of its fracture or fault plane, composes the main vein. Mineralized horsetail fractures dip into the Illinois on the hanging wall side. Surrounding the north-striking plane of the Illinois fault is a tightly compressed fold of quartzose schist, garnetiferous schist, and quartzite lenses. The rock in the trough of the compressed fold was favorable for ore emplacement because it was extensively fractured as a result of Laramide stress. The abundant pegmatites in the transition zone between hornblende gneiss and schist, shown on plate 1, contributed to the intense fracturing because of the inhomogeneity they provided during tectonic strain. The enclosing hornblende gneiss displays fractures that are tightly healed by calcite.

The ore deposit is entirely fracture-controlled. Pitchblende, the predominant ore mineral, is confined to vein fissures and their breccia zones; it is accompanied by pyrite and minor amounts of sulfides such as galena, jordisite, molybdenite, and sphalerite. The most reliable age determinations made on the pitchblende mineralization, using $^{206}Pb/^{238}U$ ratios, average around 60 m.y. (Marvin and others, 1974). Support for the 60-m.y. age is given by an entirely different method, using fission tracks in apatite. C. W. Naeser (written commun., 1976) reported a weighted age (according to number of tracks counted) of 62.4 ± 2.2 m.y. for four accessory apatites from veins and from the vicinity of veins. According to Naeser, 62.4 m.y. represents the last time the rocks cooled below about 110°C.

Table 3 shows the distribution and concentration of elements in the Schwartzwalder deposit (Young, 1979b) relative to crustal abundance. Of the seven elements besides uranium that are enriched much more than one hundred times crustal abundance, four (molybdenum, antimony, tungsten, and thallium) are high-valent constituents of uranium-bearing solutions that were entrapped in the formation of colloidal pitchblende. Silver and lead occur in widespread galena.

Pitchblende from many vein deposits worldwide is low in rare earth elements and thorium, but high in metals such as molybdenum, antimony, and tungsten. On the other hand, uraninite from pegmatites is high in rare earth elements and thorium, and low in metals such as molybdenum, antimony, and tungsten. This contrast in chemistry between uraninite from pegmatites and pitchblende from veins is shown by 43 analyses listed by Frondel (1958, p. 16–20). Some of the analyses listed as uraninites in Frondel's tabulation are almost certainly pitchblende (his analyses 21, 30, 37, 42, and 43). In almost

TABLE 3.—*Distribution and concentration of elements, relative to crustal abundance, in Schwartzwalder pitchblende ore*

[Modified from Young, 1979b; n.d., not determined]

Element[1]	Number of samples contributing to average	Average percent	Crustal abundance[2] in percent	Enrichment factor = average/crustal abundance
U	42	17.67	0.00025	70,700
Mo	42	.53	.00011	4,800
Sb	41	.11	.00005	2,200
W	42	.15	.00013	1,150
Bi	42	<.001	.0000009	<1,000
Pb	42	.96	.0016	600
As	42	<.1	.00017	<590
Ag	41	.0029	.000007	410
Tl	21	.04	.0001	400
Hg	2	>.001	.0000083	>120
Se	2	.00037	.000005	74
S	2	2.0	.047	43
Zn	42	.26	.0083	30
Cu	42	.077	.0047	16
Zr	42	.135	.017	8
Nb	42	.009	.002	5
Be	30	.0015	.00038	4
Co	5	.006	.0018	3
Y	8	.0079	.0029	3
V	42	.028	.009	3
Yb	30	<.0001	.000033	<3
Mn	30	.22	.1	2
Ni	41	.012	.0058	2
Ca	30	4.32	2.96	1.5
K	30	3.0	2.5	1.2
B	28	.001-.002	.0012	1
La	42	<.005	.0029	1
Fe	30	4.84	4.65	1
F	2	.063	.66	1
Sc	31	.001	.001	1
Ga	5	.0015	.0019	0.8
Sr	30	.02	.034	.6
Mg	30	1.12	1.87	.6
Ti	30	.2	.45	.4
Al	30	3.1	8.05	.4
Cr	42	.003	.0083	.4
Ba	30	.021	.065	.3
Si	8	2 - >10	29.5	.07->0.3
Na	5	.1	2.5	.04
Au	42	n.d.[3]	.0000004	n.d.

[1]Most elements were determined spectrographically. Seven of the U analyses were done fluorometrically. Four of the W analyses were done using a spectrophotometric isotope dilution method. Hg, Se, and S were determined instrumentally, fluorometrically, and titrametrically, respectively. F was determined using an ion electrode method. The following elements, with their detection limits (ppm) shown in parentheses, were looked for and not found: Ce (200), Nd (70), Sn (10), and Th (200).

[2]Vinogradov (1962).

[3]Sheridan and others (1967, p.100) reported traces of Au in 3 out of 30 channel samples.

all cases the difference between uraninite and pitchblende is unambiguous. Although both are mineralogically uraninite, genetic differences are blurred by classing them both as uraninite. Uraninite is macrocrystalline, usually shows good crystal form, and originates at high temperature, whereas pitchblende is microcrystalline, is usually colliform, and originates at relatively low temperature.

The Schwartzwalder deposit represents a unique set of geologic circumstances, which consist of structural complexity, nearby source rocks containing uranium, and a magmatic heat source (Young, 1979b). The absence of any one circumstance, and especially of two, would greatly diminish or eliminate chances for formation of a pitchblende vein deposit of this magnitude. Small uranium deposits and occurrences abound in this general area (Sims and Sheridan, 1964), but none approaches the Schwartzwalder deposit in economic importance. I contend that one or more of the aforementioned circumstances are missing from the small deposits and occurrences and that the Schwartzwalder probably is unique.

Figure 6, taken from Young (1979b), illustrates a possible sequence of events leading to formation of the deposit. This interpretation is consistent with the fact that the age of the intrusion (approximately 62 m.y.) is similar to the age of the deposit (approximately 60 m.y.).

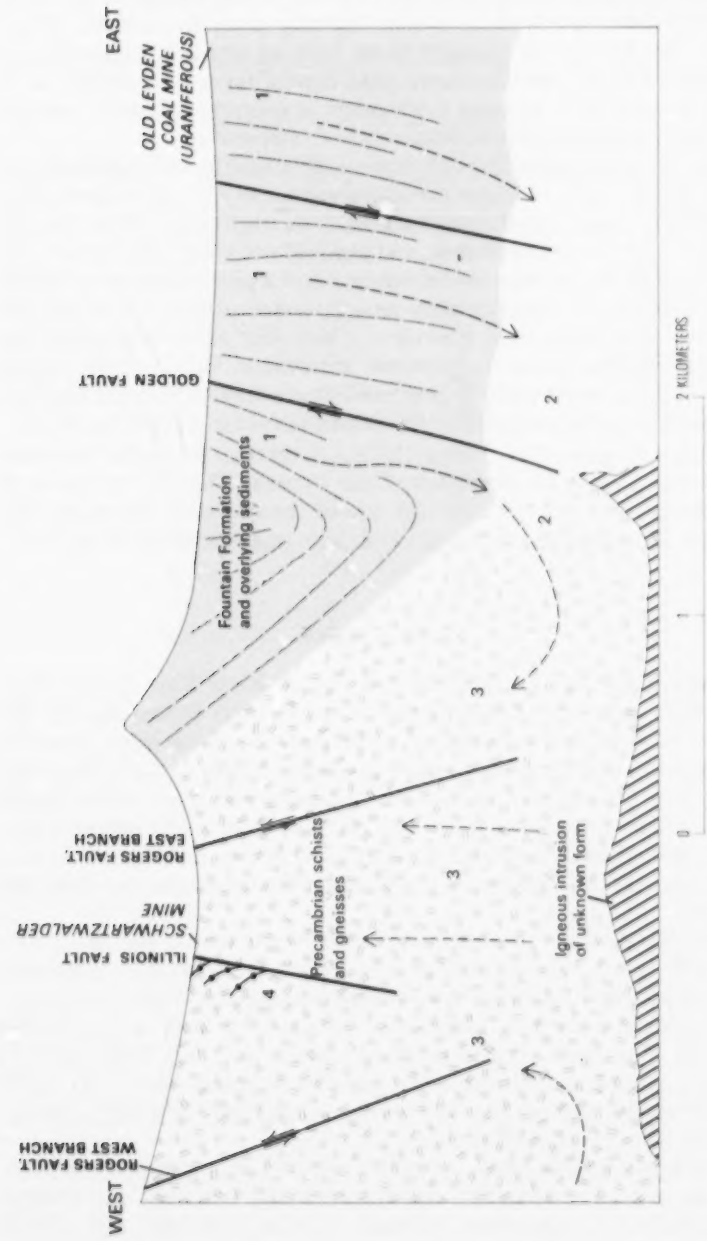
MENA MINE

Mena is the Spanish word for ore, hence Mena Mine or Ore Mine. The first discovery of pitchblende in the Ralston Buttes district was made by Fred Schwartzwalder in 1949 at the Mena Mine, formerly known as the Hoffmeister copper prospect. Access to the mine workings, now abandoned, consists of two shafts and three adits. Sparse literature on the mine is found in reports by Adams and others (1953), Sims and Sheridan (1964), Sheridan and others (1967), and Derzay and Bird (1976). Walker and Adams (1963) illustrated ore from the Mena.

The Mena Mine is located in the north-central part of sec. 26, T. 2 S., R. 71 W. (pl. 1). Production from the mine from 1956 to 1960 was approximately 2470 kg U_3O_8 (5430 lbs). Ore tenor averaged 0.27 percent U_3O_8.

The Mena vein is a mineralized breccia in a fault of the Rogers system. The fault strikes north-northwest and dips moderately to steeply northeast. Wallrocks are hornblende gneiss interlayered with minor biotite gneiss, but the granite gneiss unit lies only approximately 60 m to the northeast.

The mineralized breccia contains a network of thin veinlets of pitchblende in a mass of sulfide and other metallic minerals, and gangue, including low-temperature potassic feldspar (Sheridan and others,


EAST
OLD LEYDEN COAL MINE (URANIFEROUS)
GOLDEN FAULT
Fountain Formation and overlying sediments
ROGERS FAULT, EAST BRANCH
SCHWARTZWALDER MINE
ILLINOIS FAULT
Precambrian schists and gneisses
Igneous intrusion of unknown form
ROGERS FAULT, WEST BRANCH
WEST
2 KILOMETERS
1
0

1967, p. 80), ankerite, quartz, and calcite. The pitchblende occurs as thin (~0.5 mm) coatings on breccia fragments. Other ore minerals recorded by Sheridan and others (1967) are "hydropitchblende," chalcopyrite, pyrite, tetrahedrite-tennantite, chalcocite, bornite, galena, native bismuth, native copper, native silver[1], niccolite, pararammelsbergite?, maucherite?, covellite, and secondary copper minerals. The paragenetic sequence of mineralization seems to be, from oldest to youngest, potassic feldspar, ankerite, pitchblende, quartz, ankerite, calcite, sulfides, native metals, and sulfosalt minerals.

Two analyses of ore from the Mena, shown in table 4, indicate that five elements, bismuth, silver, arsenic, antimony, and copper, are concentrated more than uranium in this deposit. Although this deposit cannot strictly be compared to the Schwartzwalder deposit because of the great difference in magnitude, it would seem to be fundamentally different from the point of view of geochemistry. Sims and Sheridan (1964) classified the Mena as a class 3 deposit (veins in which uranium minerals are dominant), but analyses available so far would place the deposit in class 2 (uranium-bearing base-metal sulfide veins).

Sheridan and others (1967) reported a radiometric age of 73 ± 5 m.y. for the pitchblende at the Mena. These ratios and ages are as follows:

$^{206}Pb/^{238}U$: 73 ± 0.2 m.y.
$^{207}Pb/^{235}U$: 73 61.7 m.y.
$^{207}Pb/^{206}Pb$: 66 ± 57 m.y.

NORTH STAR MINE

The North Star Mine, which consisted of a short upper level and a lower adit connected with a stope that opened to the surface, is no longer accessible. When visited in October 1973, a road had been bulldozed over the workings, but copper-uranium ore was present on the dump of the former mine and scintillometer readings were over

[1] Wire silver as much as several millimeters long in late, vuggy calcite was collected by the author in 1973.

FIGURE 6 (facing page).—Diagrammatic cross section through the Schwartwalder deposit illustrating sequence of events leading to uranium deposition. Vertical and horizontal scales are the same. (1) Surface water enters steeply dipping sedimentary rocks and dissolves uranium from preexisting deposits or disseminations. (2) Descending uranium-bearing solutions are heated at depth by a Laramide igneous intrusion (the source of the nearby Ralston dike). (3) A convective pattern of water flow, caused by the intrusion, draws water from the sedimentary rocks (and also from rocks west of the Schwartzwalder deposit) and causes it to rise toward the surface along the Illinois fault and other faults. (4) With decrease in pressure and temperature, pitchblende is deposited in available openings.

TABLE 4.—*Distribution and concentration of elements, relative to crustal abundance, in two ore samples from the Mena Mine*

[See table 3. Spectrographic analyses by R. G. Havens (sample N-1) and L. A. Bradley (sample RC-157A), except as noted]

Element[1]	Sample N-1[2] Lab No. 242065 (in weight percent)	Sample RC-157A Lab No. D164644 (in weight percent)	Enrichment factor = value/crustal abundance
U	0.24[3]	<0.05	<200 - 960
Mo	.1[4]	.0015	14 - 910
Sb	.3	<.02	<400 - 6,000
W	<.01	<.01	<77
Bi	5.8[4]	.5	500,000 - 6,000,000
Pb	.12[4]	.0007	4 - 75
As	1.5	<.2	1200 - 8,800
Ag	.15[5]	.03	4000 - 21,000
Tl	<.005	<.005	<50
Hg	no analysis	no analysis	--
Se	---do-----	---do------	--
S	---do------	---do------	--
Zn	.17[4]	<.03	<3.6 - 20
Cu	10.82[4]	>10	<2100 - 2,300
Zr	.015	.003	.2 - .9
Nb	.007	.002	1 - 3.5
Be	.000[7]	.0002	.5 - 1.8
Co	.004[6]	.002	1.1 - 2.2
Y	.003	.002	.7 - 1
V	.07	.03	3.3 - 7.8
Yb	.001	.0003	9 - 30
Mn	.07	.07	.7
Ni	.008[6]	.003	.5 - 1.4
Ca	.7	7	.2 - 2
K	>10	7	2.8 - >4
B	<.002	<.002	~1
La	<.005	<.005	~1
Fe	7	3	.6 - 1.5
F	no analysis	no analysis	--
Sc	.003	.0015	1.5 - 3.0
Ga	.0007	.0015	.4 - .8
Sr	.03	.015	.4 - .9
Mg	.15	2	.08 - 1.1
Ti	.7	.15	.3 - 1.6
Al	7	3	.4 - .9
Cr	.015	.007	.8 - 1.8
Ba	.7	.002	.03 - 10.8
Si	>10	7	.2 - >.3
Na	1.5	.3	.1 - .6
Au	not detected[5]	not detected	--

[1]The following elements (with detection limits, ppm, in parentheses) were looked for and not found: Cd (50), Ce (200), Eu (100), Ge (10), Hf (100), In (10), Li (100), Nd (70), P (2000), Pd (2), Pt (50), Re (50), Sn (10), Ta (500), Te (2000), and Th (200).

[2]Sheridan and others (1967, p. 81).

[3]Analyst, J. S. Wahlberg. Analytic method: U, volumetric.

[4]Analyst, W. D. Goss. Analytic method: Bi, gravimetric; Cu, electrolytic; Mo, colorimetric; Zn and Pb, volumetric.

[5]Analyst, D. L. Skinner. Analytic method: Ag and Au, fire assay.

[6]Analysts, Claude Huffman, Jr., and R. F. Dufour. Analytic method: Co and Ni, colorimetric.

2000 cps. About 16 tons of copper ore was produced by 1916, but not until April 1952 was pitchblende discovered at the mine by Adams and others (1953).

The site is close to the center of the SE¼ sec. 23, T. 2 S., R. 71 W., in the rock unit mapped as interlayered granite gneiss and hornblende gneiss. Foliation in the mine area strikes northeast and is about vertical. The mine is also located on and near the north end of one of the northwest-trending fractures of the Rogers system. This fracture can be traced for at least 1.3 km and also passes through two springs and three copper-uranium prospects shown on plate 1.

Mineralized breccia forms a vein dipping 25°–45° northeast at the mine (Adams and others, 1953). It is perhaps significant that the only Tertiary intrusive igneous rock in the whole map area lies within 60 m of this fracture and has a roughly parallel attitude.

According to Adams and others (1953), uranium and copper minerals occur sporadically throughout the vein as fracture fillings and as interstitial material surrounding breccia fragments. Ore minerals are bornite, chalcocite, covellite, malachite, azurite, pitchblende, "hydropitchblende," uranophane, and several unidentified uranium minerals. Besides the rock breccia fragments, carbonate, potassic feldspar, and hematite staining constitute the gangue.

Table 5 gives analytic data on the ore, and the element enrichment factors indicate that ore from the North Star Mine is very similar to that of the Mena.

OTHER PROSPECTS

The six other prospects, described in this section and shown on plate 1, are minor and show geochemical affinities to the Mena and North Star Mines. All of the prospects are unnamed and have been given numbers from 4 to 9 for ease of reference. They were all visited by the writer in the latter part of 1973. Table 6 shows the results of a grab sample analysis from each prospect.

Prospect 4 is about 215 m southeast of the North Star Mine in the SE¼ sec. 23, T. 2 S., R. 71 W. It appears to be on the same fracture on which the North Star Mine is located, despite an intervening massive layer of granite gneiss. A small pit has exposed a malachite- and limonite-stained shear zone in granite gneiss and interlayered mica schist and hornblende gneiss. A small pile of ore-bearing material yielded a radiometric count of >6000 cps.

Prospect 5 is about 290 m southeast of the North Star Mine in the SE¼ sec. 23, T. 2 S., R. 71 W., and consists of a 30° inclined shaft, which is now inaccessible, driven at N. 60 E. It is on the same fracture as the North Star Mine and Prospect 4. The shaft is driven in limonite-stained pegmatite and mica schist, but hornblende gneiss and felsic gneiss are

TABLE 5.—*Distribution and concentration of elements, relative to crustal abundance, in ore samples from the North Star Mine*

[See table 3. Leaders (–) indicate no analysis or not applicable. Sample RC–167 spectrographically analyzed by L. A. Bradley]

Element[1]	Sample RC-167 Lab. No. D164643	Samples from Adams and others (1953)	Average	Enrichment factor = average/crustal abundance
U	<0.05	0.17[2]	0.11	<440
Mo	.05	--	--	460
Sb	<.02	--	--	<400
W	<.02	--	--	150
Bi	.5	--	--	556,000
Pb	.15	.1[3]	.125	78
As	.2	--	--	1,180
Ag	.015	.0159[4]	.0155	2,200
Tl	<.005	--	--	<50
Hg	no analysis	--	--	--
Se	---do------	--	--	--
S	---do------	--	--	--
Zn	.07	.19[3]	.13	16
Cu	7.0	4.17[2]	5.6	1,190
Zr	.005	--	--	.3
Nb	.003	--	--	1.5
Be	.0005	--	--	1.3
Co	.005	--	--	2.8
Y	.002	--	--	.7
V	.015	--	--	1.7
Ni	.01	--	--	1.7
Sc	.0015	--	--	1.5
Sr	.003	--	--	.1
Cr	.003	--	--	.4
Ba	.03	--	--	.5

[1]The following elements (with detection limits, ppm, in parentheses) were looked for and not found: B (20), Cd (50), Ce (200), Eu (100), Ge (10), Hf (100), In (10), Li (100), P (2000), Pd (2), Pt (50), Re (50), Sn (10), Ta (500), Te (2000), and Th (200).
[2]Average of nine analyses.
[3]Average of three analyses.
[4]Average of six analyses.

also found nearby. Malachite, chalcocite, and molybdenite were found on its small ore dump, and scintillometer readings as high as 3000 cps were recorded.

Prospect 6 is a small pit on a jeep road in the NW¼ sec. 25, T. 2 S., R. 71 W. It is also on the same fracture as Prospects 4 and 5, in fractured and limonite- and malachite-stained felsic gneiss, pegmatite, and mica schist. No anomalous scintillometer readings above a background of 220–300 cps were recorded.

Prospect 7, when visited in 1973, consisted of several pits and trenches exposing a large limonite-stained zone. A former shaft and adit shown by Sheridan and others (1967) were apparently covered. This prospect is about 18 m north of Prospect 6 and apparently on the same fracture and in similar country rock. Radiometric counts as high as 700 cps were recorded.

Prospect 8 is about 40 m west of the northwest section corner of section 25 on the east branch of Rogers fault. It consists of malachite-stained felsic gneiss rubble along the shear zone; no anomalous counts above background were detected.

Prospect 9 is near the southeast corner of the NE¼ sec. 26, T. 2 S., R. 71 W., in pegmatite and hornblende gneiss. Much yellow-brown oxidized gossan is visible in a small pit.

In summary, all of the prospects, 4 through 9, show geochemical affinities to the Mena and North Star Mines rather than to the Schwartzwalder Mine.

In addition, at least seven more prospect pits, all of which are on or close to the breccia reefs, are shown on plate 1, but they show less promise than the ones described. An exploration adit is in the NW corner sec. 31, T. 2 S., R. 70 W.

DISCUSSION

The fact that the Schwartzwalder deposit occurs in Precambrian metamorphic rock, albeit only 0.8 km from Phanerozoic sedimentary rock, has led some geologists to hypothesize that Laramide tectonism reactivated Proterozoic structures and remobilized Proterozoic concentrations of uranium (Fisher, 1976; DeVoto and Paschis, 1979; and Nelson and Gallagher, 1982). Earlier ideas invoked magmatic hydrothermal solutions (Sims and Sheridan, 1964) for all of the uranium deposits in the Front Range. Other genetic systems have been discussed by Rich and Barabas (1976), Maslyn (1978), and Young (1979b). The genetic systems advocated by these writers are somewhat different: Rich and Barabas postulated uranium-bearing solutions moving down from the surface into the Illinois fault, as does Maslyn; and Young postulated a circulatory system of meteoric water moving down and then being heated to move upward. Nevertheless their essential similarity is the lack of need for any contribution of uranium from magmatic sources.

The North Star and Mena deposits are geochemically somewhat different from the Schwartzwalder deposit, but such a difference may be misleading. It is conceivable that elements like bismuth, silver, and copper show enrichment near the surface (supergene enrichment). The Schwartzwalder was known as a copper prospect before the finding of uranium, and a bismuth value of 1.5 percent was recorded from the Minnesota level (near surface) by Sheridan and others (1967).

The fundamental difference, however, between the Schwartzwalder deposit and the North Star and Mena deposits is in the nature of the structure of their wall rocks. At the Schwartzwalder Mine many small fractures were opened in the cymoid zone, preparatory to later infilling by pitchblende, during Laramide rejuvenation of older structures. Presumably, structural conditions at the North Star and Mena

TABLE 6.—*Spectrographic analyses (in weight percent) of ore samples from six prospects in the Ralston Buttes district and enrichment factors of the detected elements*

[Samples from Prospects 4, 5, and 8 analyzed by Leon A. Bradley; samples from Prospects 6, 7, and 9 analyzed by John C. Hamilton]

Element[1]	Prospect 4 Sample RC-166[2] Lab. No. D164642	Enrichment factor[3]	Prospect 5 Sample RC-165 Lab. No. D164641	Enrichment factor	Prospect 6 Sample RC-130 Lab. No. D163357	Enrichment factor
Bi	0.003	3,330	0.003	3,330	0.003	3,330
U	.7	2,800	.07	280	<.05	<200
Ag	.015	2,140	.03	4,290	.005	714
Cu	7.0	1,490	10.0	2,130	3.0	640
Mo	.03	270	.02	182	<.0003	<2.7
Pb	.03	19	.02	13	.007	4
Be	.0015	4	.0007	1.8	.00015	.4
Zn	.03	3.6	<.03	<3.6	<.03	<4
V	.015	1.7	.015	1.7	.007	.8
Co	.003	1.7	.005	2.8	.0015	.8
Mn	.15	1.5	.07	.7	.07	.7
Nb	.0015	.8	.002	1.0	<.001	<.5
Sc	.0007	.7	.0007	.7	.0007	.7
Y	.002	.7	.003	1.0	.003	1.0
Ni	.003	.5	.01	.5	.003	.5
Cr	.003	.4	.003	.4	.0015	.2
Ba	.02	.?	.03	.5	.02	.3
Ti	.15	.3	.15	.3	.15	.3
Zr	.005	.3	.007	.4	.007	.4
Sr	.003	.1	.002	.06	.007	.2

Element	Prospect 7 Sample RC-131 Lab. No. D163758	Enrichment factor	Prospect 8 Sample RC-164 Lab. No. D164640	Enrichment factor	Prospect 9 Sample RC-144 Lab. No. D163759	Enrichment factor
Bi	0.003	3,330	0.03	33,300	<0.001	<1,100
U	<.05	<200	<.05	<200	<.05	<200
Ag	.007	1,000	.007	1,000	<.00005	<7
Cu	1.5	320	5.0	1,060	.007	1.5
Mo	.007	64	.002	18	<.0003	<2.7
Pb	.015	9	.007	4	.0015	.9
Be	.0002	.5	.0002	.5	.00015	.4
Zn	<.03	<4	<.03	<4	<.03	<4
V	.005	.6	.007	.8	.02	2.2
Co	.0007	.4	.0007	.4	.003	1.7
Mn	.1	1	.015	.2	.15	1.5
Nb	<.001	<.5	<.001	<.5	<.001	<.5
Sc	.0007	.7	.0007	.7	.002	2
Y	.002	.7	.0015	.5	.003	1
Ni	.0015	.3	.0015	.3	.005	.9
Cr	.001	.1	.0015	.2	.007	.8
Ba	.03	.5	.01	.2	.005	.1
Ti	.05	.1	.1	.2	.2	.4
Zr	.007	.4	.007	.4	.002	.1
Sr	.01	.3	.003	.1	.015	.4

[1]The following elements (with detection limits, ppm, in parentheses) were looked for and not found: B (20),Cd (50), Ce (200), Eu (100), Ge (10), Hf (100), In (10), Li (100), P (2000), Pd (2), Pt (50), Re (50), Sn (10), Ta (500), Te (2000), Th (200), Tl (50), and W (100).

[2]Sample RC-166 contains 0.003 percent B.

[3]Enrichment factor = elemental value/crustal abundance.

Mines were not as favorable. At the Schwartzwalder Mine the entire production is from a zone on the hanging wall side of the Illinois fault. This zone, no more than 200 m long and 90 m wide and extending more than 800 m downward from the surface, contains the main vein (Iilinois) and a set of horsetail veins that dip into the Illinois. It is significant that the site of virtually all the ore deposition is in the cymoid part of the Illinois where the Illinois bends northerly from its usual northwesterly trend. This is the zone in which most of the shearing and horsetail fractures developed.

On the other hand, the deposits to the north, Mena and North Star, are characterized by relatively smaller and tighter structures resulting in much less available space for mineralization.

GEOCHEMISTRY

Nelson and Gallagher (1982) hypothesized that Laramide tectonism reactivated Proterozoic structures and remobilized Proterozoic concentrations of uranium. Citing the twofold to tenfold enrichment of silver, zinc, lead, and molybdenum in the underground host rocks (close to veins, but not including vein material) from my report (Young, 1979a), they concluded that the garnet-biotite gneiss was a likely source of uranium, molybdenum, silver, and base metals.

Whatever process of ore formation has taken place at the Schwartzwalder deposit, it has resulted in the enrichment (two times crustal abundance, or more, table 3) of at least 20 elements. To achieve the enrichment of so many elements in the pitchblende veins requires a very effective concentrating process. That this process requires the presence of openings—faults, fractures, and joints—is probably best demonstrated by considering the enrichment of elements in (1) the underground host rocks (close to veins, but not including vein material), (2) the surface country rocks in the general area of the Schwartzwalder deposit, and (3) fault breccias (both within the mine and on the surface in the Schwartzwalder area).

Table 7, taken from Young (1979a), shows, based on 35 samples, the average relative abundance of elements in the underground host rocks of the Schwartzwalder deposit. The underground host rocks consist of the following samples: 10 schist, 5 garnetiferous schist, 6 hornblende gneiss, 4 quartzite, 6 interlayered hornblende gneiss and schist, 2 interlayered schist and quartzite, and 2 fault gouge and breccia.

Table 7 shows that 11 elements are enriched two times crustal abundance or more in the underground host rocks. Most of these enriched elements are the same ones that are enriched in the pitchblende veins and undoubtedly owe their enrichment to small microfractures being impregnated by ore solutions that coursed through the channels where

TABLE 7.—*Relative abundance of elements in underground host rocks of the Schwartzwalder deposit*

[Averages based on 35 samples. Crustal abundances same as in table 3]

Element	Average percent	Enrichment factor = average/crustal abundance
Se	0.000138	27.6
S	1.19	25.0
Mo	.0012	11.0
B	.0097	8.0
U[1]	.0086	5.5
Ag	.000035	5.0
Zn	.034	4.0
Pb	.0048	3.0
Sc	.0021	2.1
Mn	.198	2.0
Fe	9.3	2.0
F	.127	1.9
Cu	.0088	1.9
V	.0158	1.8
Co	.0031	1.7
Hg	.000012	1.5
La	.0035	1.2
Ni	.0061	1.1
Y	.0027	1.0
Zr	.0150	.9
Mg	1.64	.88
Ti	.0031	.7
Cr	.0061	.7
Ca	1.72	.6
Ba	.0340	.5
Be	.00019	.5
Sr	.0150	.4

[1]Equivalent uranium. Crustal abundance is based on 13 ppm thorium and 2.5 ppm uranium.

pitchblende is now found. This conclusion seems reasonable because the surface country rocks in the general area of the Schwartzwalder deposit only show enrichment in two elements, boron and fluorine, trace elements notably enriched in the Front Range.

Based on 34 samples, table 8 shows the average relative abundance of elements in the surface country rocks, which consist of the following samples: 14 schist, 7 granite gneiss, 5 quartzite, 3 garnetiferous schist, 3 hornblende gneiss, and 2 magnetite and quartz layer.

The fact that the surface country rock shows no enrichment of any

TABLE 8.—*Relative abundance of elements in surface country rocks near the Schwartzwalder deposit*

[Averages based on 34 samples. Crustal abundances same as in table 3]

Element	Average percent	Enrichment factor = average/crustal abundance
B	0.0090	7.5
F	.1820	2.8
Pb	.0030	1.9
La	.0053	1.8
Fe	6.3	1.4
Mn	.117	1.2
V	.0092	1.0
Co	.0018	1.0
Y	.0028	1.0
Zr	.0168	1.0
U[1]	<.003	~1.0
Mo	<.0005	~1.0
Cr	.0066	.8
Hg[2]	.000006	.8
Ni	.004	.7
S	.034	.7
Ba	.043	.7
Ti	.22	.5
Be	.0002	.5
Mg	.8	.4
Sr	.015	.4
Cu	.0016	.3
Ca	.7	.2

[1]Equivalent uranium. Crustal abundance is based on 13 ppm thorium and 2.5 ppm uranium.
[2]The average value for Hg is based on 29 samples.

of the elements that are enriched in the pitchblende veins is evidence that the country rock has no genetic relation to the Schwartzwalder deposit.

On the other hand, the fault breccias, table 9, show a definite genetic link with the Schwartzwalder deposit, or to put it another way, ore-forming processes in the fault breccias are the same as those that operated in the pitchblende veins. The underground fault breccias show enrichment (two times crustal abundance, or more) in 12 elements, most of which are enriched in the pitchblende veins, and the surface fault breccias show enrichment in 7 elements. Noticeable is the general diminished enrichment in the surface fault breccias, compared to the underground fault breccias, undoubtedly due to leaching by meteoric water.

TABLE 9.—*Relative abundance of elements in nine surface and two underground fault breccias*

[Crustal abundances same as in table 3. n.d., not determined]

Element	Surface fault breccias		Underground fault breccias	
	Average percent	Enrichment factor = average/crustal abundance	Average percent	Enrichment factor = average/crustal abundance
U[1]	<0.003	~1.0	0.075	300.
Mo	.0005	4.5	.0175	160.
Se	n.d.	n.d.	.00027	54.
S	.24	5.1	2.5	53.
Ag	.0001	14.	.00008	11.
Zn	<.02	<2.4	.085	10.2
Hg	.00001	1.3	.00007	8.8
Pb	.0027	1.7	.0135	8.
Mn	>.1	>1.	.3	3.
B	.002	1.7	.0030	2.5
Fe	10.	2.2	11.	2.4
V	.02	2.2	.02	2.2
Cu	.023	4.9	.008	1.7
Sc	.0015	1.5	.013	1.3
F	.243	3.7	.078	1.2
Co	.0032	1.8	.002	1.1
Mg	1.2	.6	1.8	1.
Ca	4.6	1.6	3.	1.
La	.003	1.	.0025	.9
Be	.0002	.5	.00035	.9
Zr	.009	.5	.015	.9
Y	.0025	.9	.025	.9
Ni	.0045	.8	.0045	.8
Sr	.02	.6	.02	.6
Ti	.24	.8	.2	.4
Cr	.006	.7	.0025	.3
Ba	.067	1.	.02	.3

[1]Equivalent uranium. For surface fault breccias, crustal abundance is based on 13 ppm thorium and 2.5 ppm uranium. For underground fault breccias most eU is caused by uranium; hence, crustal abundance is based on 2.5 ppm uranium.

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